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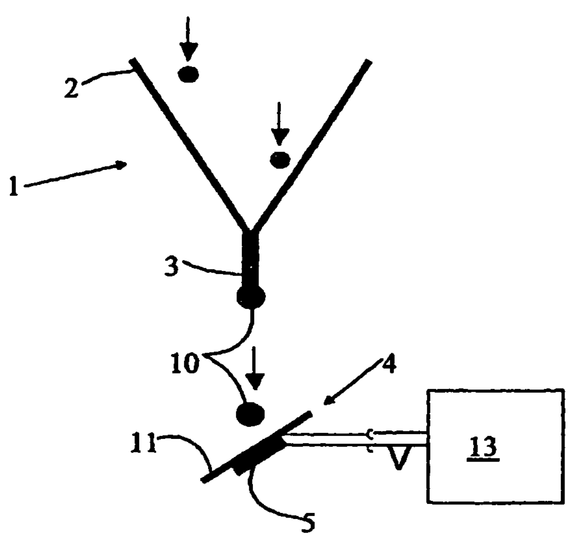
[Continued on next page]

(54) Title: PRECIPITATION SENSOR AND METHOD FOR PRECIPITATION RATE MEASUREMENT



(57) Abstract: The invention relates to a rain detector and a method for precipitation rate measurement. The rain detector comprises a collection vessel (1) of, e.g., funnel-like construction, the vessel incorporating a collector end (2) for collecting rainwater and, having a smaller cross-section, a discharge end (3) for passing collected rainwater to measurement, and a measurement section (4) located in a close vicinity of said discharge end (3) for gauging the collected rainwater. According to the invention, the measurement section (4) includes means for determining the volume of a single droplet.

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Precipitation sensor and method for precipitation rate measurement

The invention relates to a rain detector according to the preamble of claim 1.

The invention also relates to a method according to the preamble of claim 10 for precipitation rate measurement.

The invention is employed in the measurement of the intensity and total amount of rain.

The rain gauges most generally used in the art are known as counting detectors (of the tipping bucket type) comprising a funnel-like collector with a small-volume collection vessel placed thereunder. The collection vessel is arranged to empty itself automatically when a predetermined amount of water is accumulated therein, the simplest implementation being a tipping-bucket mechanism. The detector delivers a count pulse every time the bucket empties itself, whereby one pulse is calibrated to represent a predetermined amount of rain, e.g., 0.1 mm. However, this type of tipping-bucket rain gauge is hampered by certain problems a few of them being discussed below:

A basic problem is related to poor resolution of the rain gauge. This is because the resolution is determined by the volume of collection bucket. Hence, light rain accumulating to less than the tipping bucket volume remains undetected.

An additional problem arises from the "dead time" of the detector. Resultingly, water dropping from the collection funnel during the tipping of the collection bucket may remain ungauged. This defect causes measurement error particularly at high rainfall intensities.

Measurement error may also be caused by the jamming of the rain gauge due to soiling or, e.g., insects entering the detector structures.

Attempts have been made to solve these problems by means of, e.g., a detector structure having no separate collection vessel, whereby the water is allowed to exit the collector as individual droplets whose number is counted. Counting takes place so that, e.g., the falling droplets are detected as they short-circuit an electrical detector circuit (cf. US Pat. No. 4,520,667) or are counted optically (cf. international patent application PCT/DK98/00425).

A characterizing feature common to all prior-art constructions is that efforts are made to design the collector such that produces droplets of maximally standardized size irrespective of the ambient conditions and rainfall intensity. Then, the number of droplets is directly proportional to the total amount of rain. A shortcoming herein is that the construction of the droplet-forming portion of the collector becomes mechanically complicated, easily clogged and costly to manufacture. However, mechanically less complicated implementations allow the droplet size of the water exiting the collection funnel to vary with changing rainfall intensity thus causing measurement error (cf. Stow et al., Journal of Atmospheric and Oceanic Technology, Vol. 15, pp. 127-135).

It is an object of the present invention to overcome the problems of the above-described prior art and to provide an entirely novel type of rain detector and method for measuring rainfall data.

The goal of the invention is achieved by a collector construction comprising a funnel-like collection vessel, wherefrom rainwater exits as single drops, and a sensor that is functionally integrated with the collector and provides an output signal proportional to the size of the droplet exiting the collector.

More specifically, the rain detector according to the invention is characterized by what is stated in the characterizing part of claim 1.

Furthermore, the method of rain detection according to the invention is characterized by what is stated in the characterizing part of claim 10.

The invention provides significant benefits.

The invention facilitates a very uncomplicated and low-cost mechanical construction inasmuch as it allows variations in the droplet size. The collector may be designed into a funnel, for instance, that has a straight discharge tube. Thus, soiling or partial clogging of the collector does not cause a measurement error provided that the collected water can exit via the discharge tube under all conditions. Resultingly, any measurement error related to varying droplet size can be eliminated.

In the following, the invention will be examined in greater detail with the help of exemplifying embodiments illustrated in the appended drawings in which

FIG. 1 is a schematic view of a first embodiment of a rain detector according to the invention based on a force sensor;

FIG. 2 is a schematic view of a second embodiment of a rain detector according to the invention based on a capacitive sensor;

FIG. 3 is a block diagram of a third embodiment of a rain detector according to the invention based on a charge sensor;

FIG. 4 is a block diagram of a fourth embodiment of a rain detector according to the invention based on an optical detection system; and

FIG. 5 is a graph representing the pulse signal generated by a water droplet in a system according to the invention.

As mentioned above, a rain detector according to the invention comprises:

1) a collector having, e.g., a funnel-like shape wherefrom rainwater exits as single drops and, functionally integrated thereto,
2) a sensor capable of delivering an output signal proportional to the size of the falling droplet.

The relationship between the droplet volume and detector output signal is resolved by either laboratory or field tests. Herein, the total amount of rain can be determined from the output signal values by recording the volumes of the single droplets and then summing up the same. The rain intensity is obtained by computing the change in the accumulated rainfall over a predetermined measurement cycle.

Counting of droplet number and volumes can be implemented in plural different ways by virtue of, e.g., piezoelectric, capacitive, optical or droplet-charging techniques as follows.

Detection based on a force sensor

FIG. 1 illustrates schematically the principle of droplet detection based on a force sensor such as a piezoelectric transducer. According to the invention, the rain detector comprises a collection vessel 1 having a large-area collection vessel 2 and a small-area discharge end 3. Typically, this kind of collector 1 is funnel-shaped. Droplets falling from the discharge end 3 of the collector 1 impinge on a detector plate 11 of rain detector 4 whereto is connected a piezoelectric force sensor 5. The force imposed by the droplet 10 on the detector plate is dependent on the droplet size whereby also the magnitude of the voltage pulse generated by the sensor is proportional to the size of droplet 10.

Particular advantages of piezoelectric detection are in the first hand that the detector portion can be made entirely hermetically sealed so that the electronics of the system is protected from humidity and dirt. Secondly, the power dissipation of the measurement system can be easily minimized using a microprocessor designed to include a so-called "sleep-mode" function. Resultingly, if no droplets are detected falling from

collector 1 within a given time set in the microprocessor control program, the microprocessor sets the measurement electronics into a so-called sleep mode of minimal power consumption. The microprocessor can be awakened by taking a control signal to a given input thereof. When rainfall detection takes place using a piezoelectric sensor, the voltage pulse delivered by the sensor may be used as the awaken signal, whereby the measurement electronics circuitry assumes the measurement mode immediately when the first raindrop falls on the rain detector. The force sensor may also be implemented using, e.g., a capacitive acceleration sensor, a sensor made from conductive plastic or a sensor made from piezoelectric polymer. The droplet volume is determined computationally in block 13. In lieu of using direct force measurement, the force sensor may also include force-transmitting constructions such as lever structures and the like.

The determination of droplet volume takes place as follows. When hitting the detector plate 11, the rainwater droplet inflicts thereon a force transmitted further to force sensor 5 and then indicated at the output thereof as a voltage pulse. The waveform of the pulse is recorded in memory and analyzed for at least one parameter known to be proportional to the droplet volume. Suitable parameters in this sense are, e.g., the peak-to-peak voltage (Vpp), the maximum or minimum voltage of the pulse or the full-width value at half maximum (w½). The typical pulse waveform and parameters determined therefrom are shown in FIG. 5.

In certain cases the sensor response may also be affected by factors other than the droplet size, such as temperature, for instance. The values of these variables can, however, be measured by means of additional sensors and then be included in computation as supplementary parameters.

Now, the droplet volume is computed using formula

$$V = f(p1,\ldots pn, q1,\ldots qm)$$

where V is the droplet volume, p1...pn are the values of the measurement parameters known to be dependent on the droplet size and q1...qm are the values of the supplementary parameters such as temperature values. Function f, which is determined by laboratory or field tests, represents the dependence between the parameters mentioned above.

Detection based on a capacitive technique

The operating principle of this detector implementation is shown in FIG. 2. The discharge tube 3 of collector 1 is made from a conductive material and has a conductive ring 12 of larger diameter placed thereunder. The detector senses the capacitance between the discharge tube 3 and the underlying external ring 12. Inasmuch as rainwater under all circumstances is at least slightly conductive, the droplet formed at the exit orifice of the discharge tube acts as a conducting electrode in the capacitance measurement circuit. Resultingly, also the capacitance between the discharge tube 3 and the external ring 12 increases with the increasing size of the hanging droplet until the droplet 10 falls and the capacitance assumes its initial value. The change in the capacitance at the fall of droplet 10 is proportional to the size of droplet 10, thus being suitable for use as the detector output signal. The droplet volume is determined computationally in block 13.

Detection based on sensing electrical charge of droplet

The operating principle of this technique and an exemplary embodiment of its measurement electronics circuitry are shown FIG. 3. Herein, droplets 10 falling from collector 1 are charged by a DC voltage. The magnitude of charge assumed by the droplet is proportional to the surface area of droplet 10 and, hence, on its volume. Droplet 10 is arranged to fall on an underlying conductive electrode 14 which is connected to the input of a charge-sensitive amplifier 15. Resultingly, the output of the measurement circuit delivers a signal proportional to the charge assumed by the droplet, which in the implementation shown in diagram is a burst of pulses wherein the number of pulses is proportional to the charge of the droplet. Obviously, also

other techniques of charge measurement may be used as well. The volume of droplet 10 is determined from its charge computationally in block 13.

Optical detection

Detection may also be implemented using optical techniques as shown in FIG. 4, for instance by arranging the falling droplet to interrupt a light beam transmitted in an optical detection unit 9 from a light source 11 to a photodiode 12 or the like sensor. Since in this technique it occurs that the larger the droplet diameter the longer the duration of the light beam interruption, it is possible to use the duration of the light beam interruption as the detector output signal. The droplet volume is determined from the output signal of the optical detector in block 13.

In the context of the present application, electrically responsive plastic is understood to mean a polymer material in which some electric quality can be affected by an external force imposed thereon. This type of electric parameter may be conductivity, specific capacitance or the like variable.

The funnel of the apparatus may also be arranged heatable. Particularly in the detector of snowfall, a rain detector equipped with a heatable funnel can deliver information on the precipitation rate and the water value of the snowfall.

What is claimed is:

1. A rain detector comprising

– a rainwater collection vessel (1) of, e.g., funnel-like construction, the vessel incorporating a collector end (2) for collecting rainwater and, a discharge end (3) having a smaller cross-section, for passing collected rainwater to measurement, and

– a measurement section (4) located in a close vicinity of said discharge end (3) for gauging the collected rainwater,

characterized in that

– said measurement section includes means (4, 13) for determining the volume of a single droplet.

2. The rain detector of claim 1, **characterized** in that the measurement section (4) includes a force sensor (5) which is adapted on the fall path of the single droplet and serves in the volume determination of the falling droplet from the detected mass of the droplet.

3. The rain detector of claim 1 or 2, **characterized** in that the force sensor is a piezoelectric sensor.

4. The rain detector of claim 1 or 2, **characterized** in that the force sensor is a capacitive acceleration sensor.

5. The rain detector of claim 1 or 2, **characterized** in that the force sensor is a sensor made from an electrically responsive polymer material or a piezoelectric plastic material.

6. The rain detector of claim 1, **characterized** in that the measurement section includes a capacitive sensor (6) adapted on the path of the falling droplet and capable of determining a capacitance value proportional to the volume of the falling droplet and the rain detector further includes means (13) for determination of droplet volume on the basis of the measured capacitance value.

7. The rain detector of claim 1, **characterized** in that the measurement section includes means (7) for charging the falling droplet with an electric charge, complemented with measurement means (8) for sensing the value of the charge assumed by the droplet, and computational means (13) for determination of droplet mass on the basis of the sensed droplet charge value.

8. The rain detector of claim 1 with optical means (9) for measuring precipitation rate, **characterized** in that the rain detector additionally includes means (13) for determining droplet volume from the optical means output signal.

9. The rain detector of any one of foregoing claims, **characterized** in that the precipitation collection funnel is adapted heatable.

10. A method for precipitation rate measurement comprising the steps of

- collecting precipitation by means of a rainwater collection vessel (1) of, e.g., funnel-like construction, the vessel incorporating a collector end (2) for collecting precipitation and, a discharge end (3) having a smaller cross-section, for passing collected precipitation to measurement, and

- measuring the collected precipitation in a measurement section (4) located in a close vicinity of said discharge end (3),

characterized in that

– the volume of each single droplet of precipitation exiting said discharge end (3) is determined in said measurement section.

11. The method of claim 10, **characterized** in that the force impacted by the falling droplet is measured in order to determine the volume of the falling droplet.

12. The method of claim 10 or 11, **characterized** in that the droplet impact force sensor is a piezoelectric sensor.

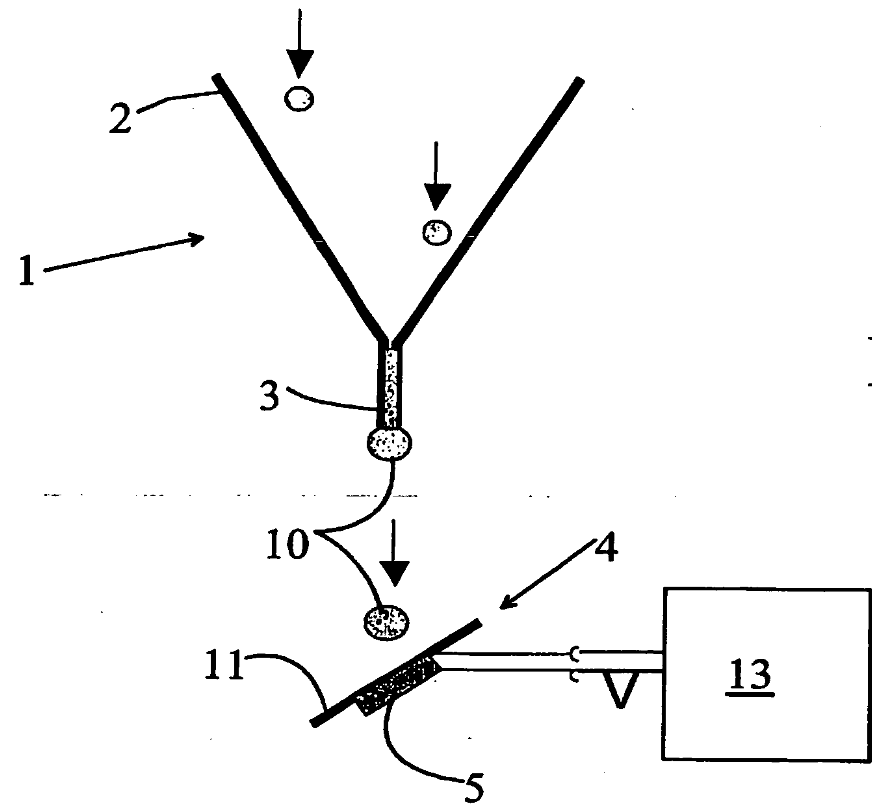
13. The method of claim 10 or 11, **characterized** in that the droplet impact force sensor is a capacitive acceleration sensor.

14. The method of claim 10 or 11, **characterized** in that the droplet impact force sensor is a sensor made from an electrically conductive polymer material or a piezo-electric plastic material.

15. The method of claim 10, **characterized** in that the method comprises the step of determining a capacitance value which is proportional to the volume of the falling droplet and thus can be used in the determination of the droplet volume.

16. The method of claim 10, **characterized** in that the method comprises the steps of charging the falling droplet with an electric charge and measuring the value of the charge assumed by the droplet, wherefrom the droplet volume is further determined.

17. The method of claim 10, **characterized** in that an optical techniques is employed in the determination of droplet volume.



Fig, 1

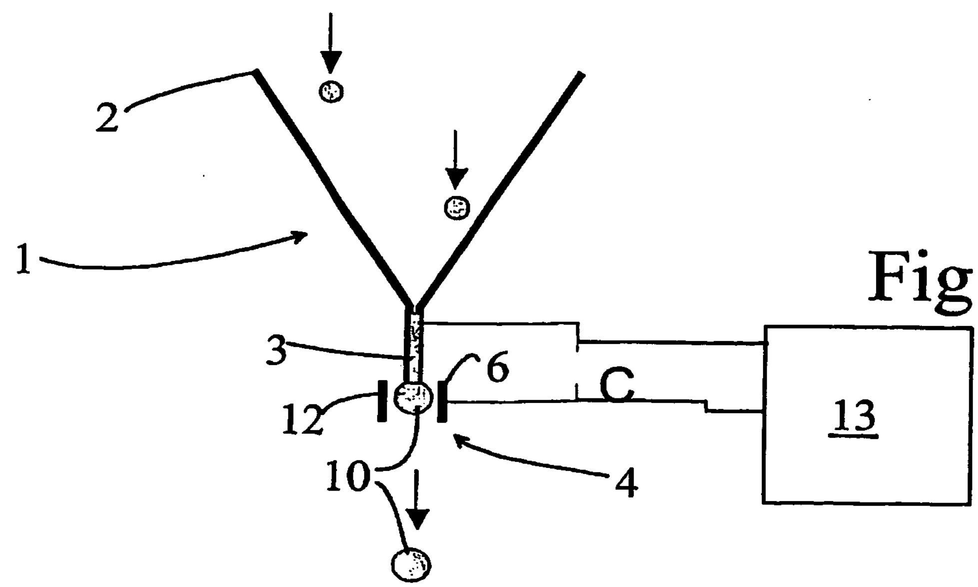


Fig. 2

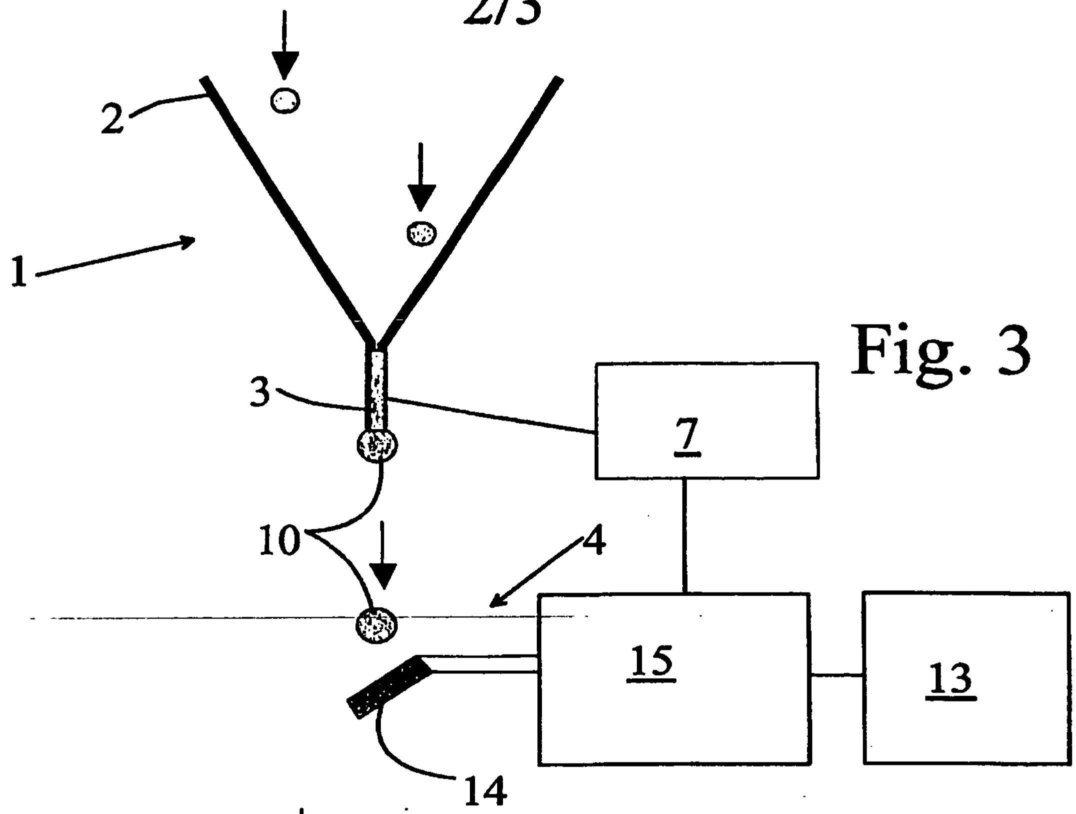


Fig. 3

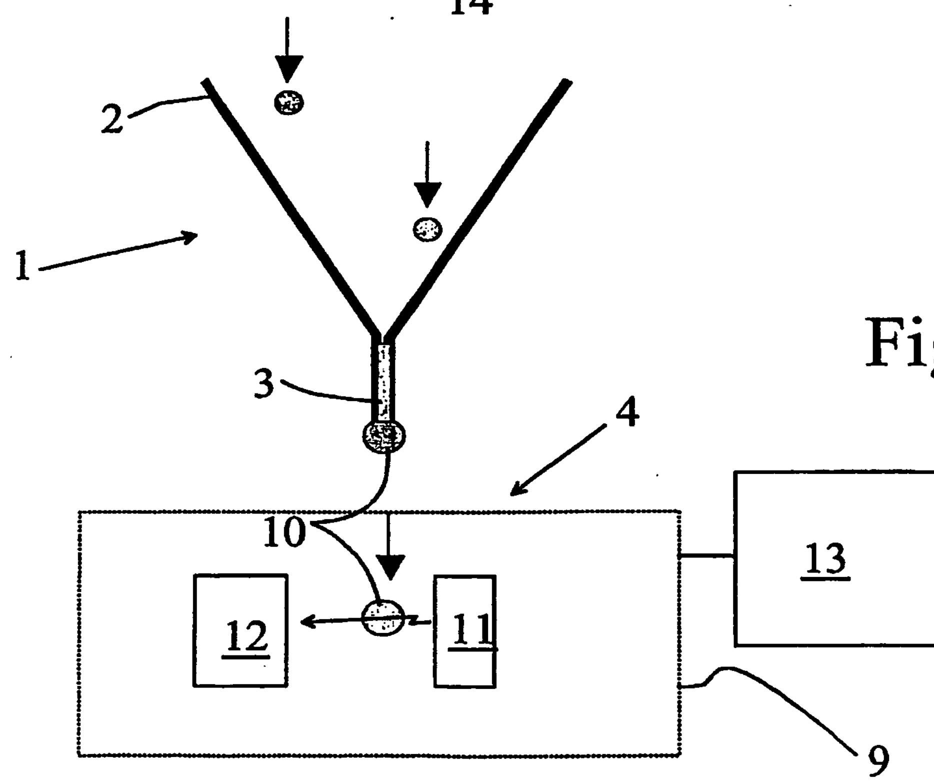


Fig. 4

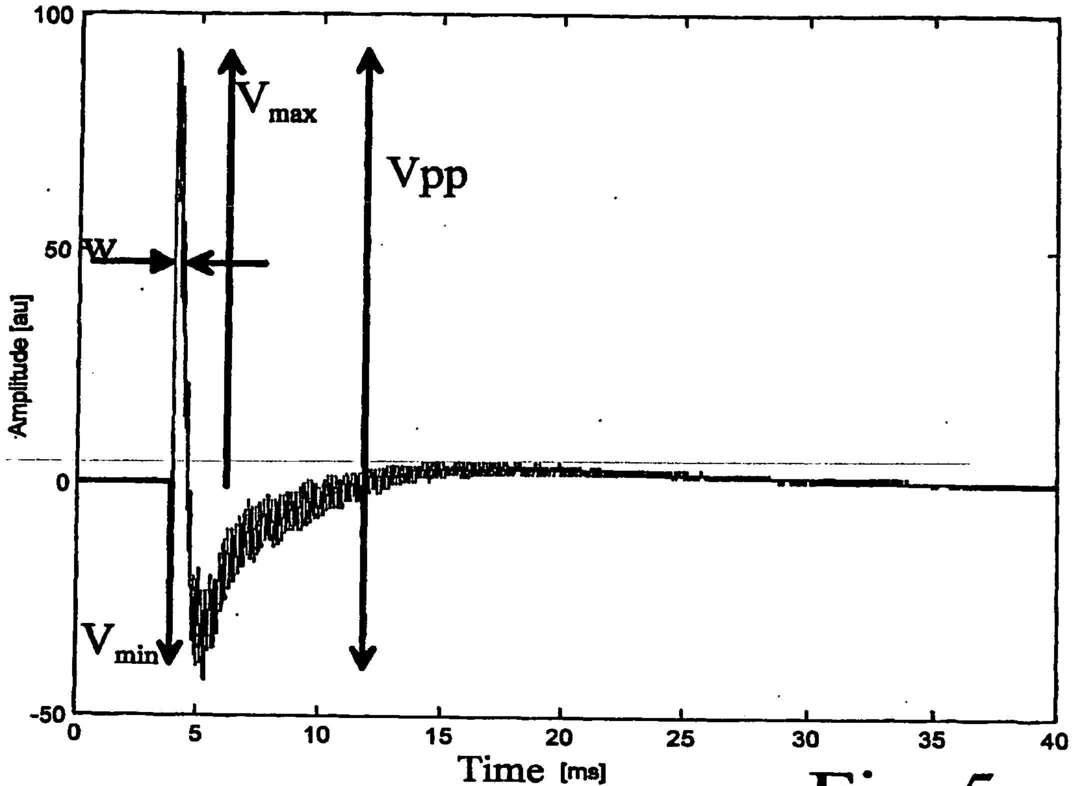

100
50
0
-50
Amplitude [au]
0
5
10
15
20
25
30
35
40
Time [ms]
V_{max}
Vpp
W
V_{min}

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI 02/00759

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: G01W 1/14
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: G01W

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	FR 2612648 A (SOCIETE CLIMAGRO S.A.R.L.), 23 Sept 1988 (23.09.88)	1-5,10-14
Y		9
	--	
X	WO 9800736 A1 (ALKA ELECTRONIC APS), 8 January 1998 (08.01.98)	1-5,8,10-14, 17
	--	
X	EP 0360892 A1 (GENRICH, VOLKER), 4 April 1990 (04.04.90)	1,6,7,10,15, 16
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[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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Date of the actual completion of the international search	Date of mailing of the international search report
12 December 2002	17 -12- 2002
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer KARIN JANSDOTTER/BS Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI 02/00759

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol.015, no. 84 27 February 1991 (1991-02-27) & JP 02 300692 A (JAPAN RADIO CO LTD), 12 December 1990 (1990-12-12) abstract --	1,8,10,17
X	PATENT ABSTRACTS OF JAPAN vol.016, no. 357 31 July 1992 (1992-07-31) & JP 04 110692 A (SUMITOMO HEAVY IND LTD), 13 April 1992 (1992-04-13) abstract --	1,8,10,17
Y	FR 2770306 A1 (METEO-FRANCE ETABLISS PUBLIC A CARACT ADMINISTATIF), 30 April 1999 (30.04.99) --	9

INTERNATIONAL SEARCH REPORT
Information on patent family members

28/10/02

International application No.
PCT/FI 02/00759

Patent document cited in search report			Publication date	Patent family member(s)			Publication date
FR	2612648	A	23/09/88	NONE			
WO	9800736	A1	08/01/98	AU	3254697	A	21/01/98
				DK	72796	A	03/01/98
EP	0360892	A1	04/04/90	NONE			
FR	2770306	A1	30/04/99	NONE			